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Evaluation of Maize (Zea mays L.) Hybrids for Grain Yield and Nitrogen Use Efficiency under Moisture stress Areas of Ethiopia

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Abstract

Maize is an important food security crop in central rift valley of Ethiopia. Applying excess Nitrogen fertilizer in maize production entails costs to smallholder farmers and results in nitrous oxide emission to the atmosphere exacerbating the problem of climate change. Screening nitrogen use efficient hybrids enables resource poor farmers to reduce cost of production, maintain environmental pollution and enhance crop productivity. This experiment was conducted to determine the effect of nitrogen fertilizer on yield and yield related traits and assess the relationship between yield and nitrogen use efficiency indices. Eight maize hybrids were evaluated at three rates of N fertilizer (0, 32.5 and 65 kg N/ha) using split-plot design with three replications at two locations (Dera and Melkassa) in 2020 main cropping season. The results from analysis of variance (ANOVA) at each location indicated that majority of yield and yield related traits, agronomic and physiological efficiency were significantly influenced either by one or two of the factors (nitrogen and genotype) and/or the interaction effect of the two at both locations. The results of combined ANOVA over locations revealed that the interaction of the three factors (location, nitrogen and genotype) had significant effect on leaf area index, number of kernel per ear, agronomic and physiological efficiency. The hybrids grain yield ranged from 3489 (MH138Q) without nitrogen fertilizer to 8390 kg ha-1 (WE8206) due to application of 65 kg N ha-1. Thus, WE8206 and WE7210 could be recommended for production in the study areas. However, for reliable recommendation the experiment has to be repeated for one more season at both locations.

Keywords: Agronomic efficiency; Grain yield; Nitrogen use efficiency; Physiological efficiency

Introduction

Maize (Zea mays L.) is one of the members of the grass family, Gramineae. Its center of origin is accepted to be in Mesoamerica, primarily Mexico and the Caribbean though there is some controversy on the origin of the crop (Purseglove, 1976). It is cultivated globally being one of the most important cereal crops worldwide. In 2018, the three cereals (wheat, rice and maize) were cultivated on more than 672 million hectares of which maize accounted 41.6% land, and it had the widest distribution than the two cereal crops (FAO STAT, 2020). Maize was cultivated in 166 countries which were more than by 49 and 44 % than rice and wheat, growing countries respectively (CONABIO, 2017). Its high environmental adaptability to diverse climatic conditions and it is grown from sea level to higher than 3000 m.a.s.l. and in areas receiving annual rain fall of 250 to 5000 mm (Downsell et al., 1996). The crop is being directly consumed as food, used as feed and for the production of fructose/glucose, flour, oils and ethanol. As a result of this versatility, adaptability and productivity, maize has become the most abundant crop globally (CONABIO, 2017) [1,2].

In 2018/19 Meher season, maize is produced by 9,863,145 smallholder farmers on 2,367,797.39 hectares of land and produced 9,492,770.834 tonnes of grain yield with average yield of 3.99 t/ha (CSA, 2019). The average national maize yield was lower than 5.5 t/ha of the world's average yield (FAO, 2019). The predominant constraints of maize production in Ethiopia are related to frequent occurrence of drought, low soil fertility, poor agronomic practice, limited use of input, insufficient technologies, lack of credit facilities, poor seed quality, diseases, insects and weeds (CIMMYT, 2004; Mosisa et al., 2012) [3].

Climate change and variability pose a serious threat to food production in sub-Saharan Africa (Fosu-Mensah et al., 2019). Climate change contributed significantly to the water scarcity problem (WHO, 2009). The changes in temperature and precipitation affect crop photosynthesis, crop development rates, as well as water and nutrient availability to crops (Steve and Paul, 1991). It was indicated that an increase in temperature of 2° C or more in the late 20th century was expected to negatively affect major crops (i.e. wheat, rice, and maize) on both temperate and tropical regions (IPCC, 2012) [4].

Nitrogen is the main limiting nutrient after carbon, hydrogen and oxygen for photosynthetic process, growth-development of plants and other changes to complete its lifecycle. Excessive use of N fertilizer results in enhanced crop production costs and atmospheric pollution; thus there is an urgent need to up-grade nitrogen use efficiency in agricultural farming system (Muhammad et al., 2020). Therefore, the water scarcity and temperature increase as constraints of maize production in moisture stress areas might not overcome unless the tolerant varieties to moisture stress are also efficient for N use. One of the major goals of crop research program is reducing fertilizer input while maintaining the environment or even increasing crop yield (Matson et al., 1997; Tilman et al., 2002). However, genetic selection for improved nitrogen use efficiency (NUE) is often ignored and the genetic improvement of NUE in maize breeding program is mainly achieved through indirect selection for increased hybrid yield performance (Moll et al., 1982; Below et al., 2013) [5]. In Ethiopia, 100 kg Urea and 100 kg NPS (65 kg N/ha) fertilizers are recommended

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for maize production for all the six major maize agro-ecology zones. However, the overall Ethiopia`s average fertilizer use is low and stands at approximately 21 kg/ha (Aweke, 2018). Particularly, the small-scale farmers in moisture stress areas often do not invest in yield enhancing inputs like nitrogen fertilizer, because it contributes to lower crop productivity (CIMMYT and IITA, 2010) [6].

Evaluation and identification of inbred lines and QPM hybrids tolerant to low N were reported (Addisalem, et al., 2019; Buchaillot et al., 2019). Limited research were conducted on fertilizers rates determination for maize production in central rift valley but it was not on maize genotypes developed to tolerant to low N and moisture stresses (Sime and Aune, 2014; Hawi, et al., 2015). Melkassa Agriculture Research Center identified three way cross hybrids for moisture stress areas after evaluation for many years and over locations under managed drought stress and rain-fed conditions. However, these promising maize hybrids were not evaluated to N use efficiency, reducing the cost of production, enhance productivity of maize while maintaining environmental quality [7]. Thus, the determination of NUE of these hybrids helps breeders in making decision and recommendation of better varieties which are efficient to N uptake and utilization that satisfies the interest of resource poor farmers to produce higher yield of maize with low input and cost in dry lowlands of the country. Therefore, the objectives of this study was to determine the genetic variability of maize hybrids for yield, yield related traits and nitrogen use efficiency under varying levels of N in moisture stress areas of Ethiopia [8].

Materials and Methods

Description of experimental sites

The field experiment was conducted during 2020 main cropping season at two locations (Dera and Melkassa) in the Central Rift Valley of Ethiopia representing semi-arid maize growing environments (drought prone areas) in Ethiopia (Table 1).

Experimental materials

Eight maize hybrids including two standard checks were used at a test crop at two locations (Dera and Melkassa. The six QPM (Quality Protein Maize), a three way cross hybrids were developed for moisture stress areas and selected as better performing hybrids in yield, drought tolerance, rust and TLB diseases from national variety trials. The two check varieties viz. MH 138Q and MH 140 are medium maturing QPM and non-QPM hybrid, respectively, and both varieties were released by Melkassa Agricultural Research Centre. The quality protein maize, MH 138Q is a three way cross hybrid released in 2012, whereas as MH 140 (non-QPM) is also a three way cross hybrid released in 2013. All these hybrids are categorized under a medium physiological maturity group. The list and description of eight maize hybrids (Table 2) [9].

Treatments and experimental design

The treatments consisted of factorial combinations of eight maize hybrids and three N levels (0, 32.5 and 65 kg N/ha) laid out in a split plot design with three replications. Nitrogen rate was assigned as main plot and the genotypes were assigned as sub plot. The plot size for planting was 4 m × 4.5 m (18 m2) accommodating 6 rows of 0.75 m and 0.25 m inter-and intra-row spacing, respectively. The data was collected from the net plot size of 9m2 of four middle/central rows of each plot leaving the outside rows and a distance of 50 cm at the ends of each middle row to serve as borders. The distance between the plots and blocks were kept at 1m and 1.5 m apart, respectively [10].

Experimental procedures

The experimental plots were prepared by tractor plowing and harrowing. In accordance with the specifications of the design, a field layout was prepared and each treatment was assigned randomly to experimental plots within each block independently [11]. The treatments of N soil nutrient were arranged based on the fertilizers recommendation for maize viz. 100 kg/ha Urea (46% N) and 100 kg/ha NPS/Nitrogen, Phosphorus and Sulfur (19% N, 38 % P2O5 and 7% S). Therefore, The recommended rate of NPS was placed together with the seeds (two seeds per holes) during planting on June 26/2020 and July 14/2020 main cropping season at Melkassa and Dera sites respectively, while N was applied in a split application when plants was at jointing with approximately a 60-cm plant height or knee height and at flowering/anthesis as top dressing. The fertilizer after application was covered with the soil immediately to avoid its loss to the air through volatilization. Two seeds was planted per holes at a spacing of 25 cm intra raw and thinned to 1 plant per stand. Hand weeding was undertaken using a local hand hoe after three weeks of planting [12].

Plant tissue sampling and analysis

At crop maturity, a sub-sample from each net plot was harvested

Table 1: Description of experimental sites.

Locations	Geographical position		Soil types	Altitude (m.a.s.l)	Rain fall (mm)	Temperature (^{0}c)	
	Latitude	longitude				Min	Max
Dera	8^0 04` N	39^0 00` E	Andosols	1660	616.86	6.6	26.19
Melkassa	8^0 26` N	39^0 22` E	Andosols	1550	763	14	28
Source: Melkassa Agricultural Research Center							

Table 2: Description of Experimental Materials.

S.N	Genotypes	Pedigree	Year of released	Original source
G1	WE5202	WMA2101/WMC8801//CML539	-	MONSATO -South Africa
G2	WE6205	WMA3104/WMA2001//CML539	-	MONSATO -South Africa
G3	WE7201	WMC5813/WMC8801//CML539	-	MONSATO -South Africa
G4	WE7210	CML539/WMB0001//WMA2002	-	MONSATO -South Africa
G5	WE8203	WMB3002/WMB4810//WMA2502	-	MONSATO -South Africa
G6	WE8206	WMB3002/WMB4810//WMA2230	-	MONSATO -South Africa
G7	MH138Q	CML144/CML159//POLL15#SR538	2012	CIMMYT
G8	MH140	CML444/CML547//ZL0814	2013	CIMMYT
Seed source: Melkassa Agricultural Research Center (MARC)				

at ground level and dried at 70 °C until constant weight was reached for dry weight determination and partitioned into straw and grain. The dried samples were milled, and the grain and straw N content of the plant samples were determined using the micro-Kjeldahl method as stated by American Association of Cereal Chemists (AACC, 2000). The laboratory analysis was done at Melkassa Agricultural Research Center, Soil Laboratory [13].

Data collection

Phenology, growth, yield and yield components data were collected. Crop growth rate was suggested by Watson (1956). The CGR explains the dry matter accumulated per unit land area per unit time (gm-2 day-1).

CGR= (W2-W1) p(t2-t1)

Where, W1 and W2 are whole plant dry weight at time t1 – t2 respectively.

ρ is the ground area on which W1 and W2 are recorded.

CGR of a species are usually closely related to interception of solar radiation

Nitrogen use efficiency (NUE) evaluated in terms of agronomic efficiency and physiological efficiency. Agronomic efficiency was determined as kg grain produced per kg of nitrogen applied, whereas physiological efficiency was determined as kg grain produced per kg of nutrient uptake. It was calculated using the equation established as agronomic efficiency and physiological efficiency by (Fageria and Baligar, 2005) as below [14].

Agronomic efficiency (AE) = Gf¬- Gu= kg grain/kg N-fertilizer

Na

Where Gf is the grain yield in the fertilized plot (kg), Gu is the grain yield in the unfertilized plot (kg), and Na is the quantity of nutrient applied (kg).

Physiological efficiency (PE) = Yf - Yu = kg kg-1

Nf - Nu

Where Yf is the total biological yield (grain plus straw) of the fertilized plot (kg), Yu is the total biological yield in the unfertilized plot (kg), Nf is the nutrient accumulation in the fertilized plot (kg), and Nu is the nutrient accumulation in the unfertilized plot (kg) [15].

Data analysis

Data collected from each location was subjected to analysis of variance (ANOVA) for individual location and combined ANOVA over location was also done using the procedure of SAS version 9.2 (SAS Institute, 2008). F-ratio homogeneity test was conducted to error variances as outlined in (Gomez and Gomez, 1984). Following the presence of significant difference among hybrids for parameters, the mean values of maize hybrids was compared using least significant test (LSD) at 5% probability level [16].

Results and Discussions

Soil physico-chemical properties of the experimental sites

The results of physical and chemical analyses of the soil sample for each location. The textural class of the soils was sandy loam and sandy-clay loam at Dera and Melkassa sites respectively. The soil pH was neutral for Melkassa site and moderately alkaline for Dera as per the rating suggested by (Tekalign, 1991) [17]. According to (FAO, 2008), suitable pH range for most crops is between 6.5 and 7.5 in which N availability is optimum. Thus the results of soil test indicated the suitability of the soil reaction in the experimental sites for optimum crop growth and yield (Table 3).

The soil organic matter content (OM) (1.56 and 2.10%), total nitrogen (TN) (0.09 and 0.12%), organic carbon (OC) (0.91 and 1.23%) and cation exchange capacity (CEC) (0.3 and 1.0 cmol kg-1 soil) were low at Dera and Melkassa sites respectively, as suggested by (Berhanu, 1980; Tekalign, 1991 and FAO, 2006). According to the rating suggested by Olsen et al. (1954), the soil for the two sites had medium available P content (Dera, 5.02 ppm and Melkassa, 6.12ppm) but slightly saline soil at Dera site. As suggested by (EthioSIS, 2016), the N nutrient of the soils at both sites were low; hence, amending the soils of the sites with fertilizer was important for enhancing crop yield as well as soil health [18].

The soils of the study sites had higher sand to clay ratio at (Dera, the sand to clay ratio is 3.63:1.and at Melkassa the sand to clay ratio is 1.73:1), low organic matter and low organic carbon. This indicated that the soil fertility of the two sites was low. If the CEC is low, it is necessary to consider the increasing inputs of organic matter through additional inputs of organic materials (Botta, 2015). According to (Aweke, et al., 2014), loss of soil organic matter due to topsoil erosion along with poor physicochemical properties is the prominent causes for the

Table 3: Physicochemical properties of soil at Dera and Melkassa sites before planting maize in 2020 main cropping season.

Location					
Soil property	**Dera**			**Melkassa**	**Reference**
Physical properties	Value	Rating	Value	Rating	
Sand (%)	58		52		
Silt (%)	26		18		
Clay (%)	16		30		
Textural class		Sandy loam		Sandy-clay loam	Tekalign (1991)
Chemical properties					
pH	7.41	Moderately alkaline	7.3	Neutral	Tekalign (1991)
Total N (%)	0.09	Low	0.12	low	Tekalign (1991)
Av. P (ppm)	5.02	Medium	6.12	Medium	Olsen et al. (1954)
OC (%)	0.91	Low	1.23	Low	Tekalign (1991)
OM (%)	1.56	Low	2.1	Low	Berhanu (1980)
CEC (cmol(+)kg	0.3	Low	1	Low	FAO (2006)
N (%)= percentage of total Nitrogen, P=Phosphorus, OC (%)= Percent Organic Carbon, OM (%)=Percent Organic Matter and CEC (cmol(+) kg = Cation Exchange Capacity					

deterioration of soil fertility and productivity. Balanced and careful use of external inputs together with eco-friendly and environmentally sounds soil management practices are essential issues for sustainable agriculture production (Kumar et al., 2015) [19].

Weather conditions of the experimental sites

The weather condition of the experimental sites in 2020 cropping season are presented in (Figure 1 and Figure 2). The two sites received rainfall every month starting from March 2020 in which the Dera and Melkassa sites received the maximum 165.9 and 248.5 mm rainfall respectively. The lowest precipitation for Dera site was 2.1mm received during October 2020 while, Melkassa site received the lowest rainfall

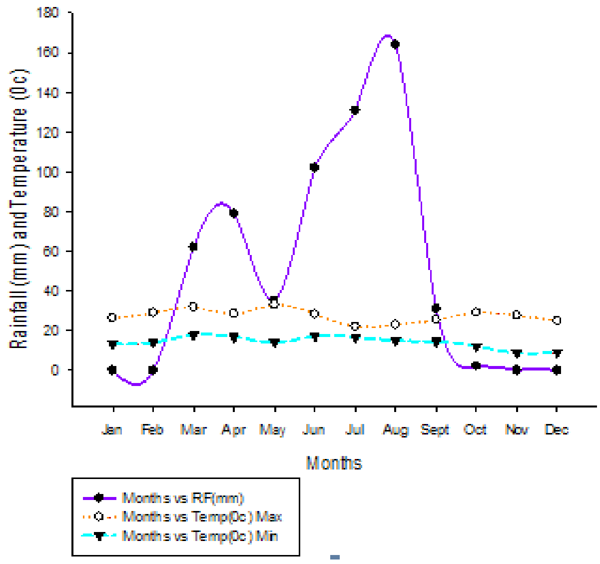

Figure 1: Monthly precipitation, maximum and minimum temperature at Dera site during 2020 main cropping season.

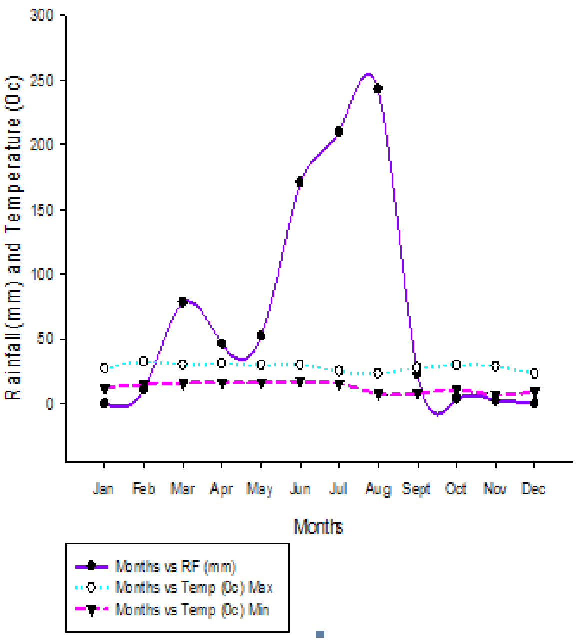

Figure 2: Monthly precipitation, maximum and minimum temperature at Mekassa site during 2020 main cropping season.

during November (1.1mm). The total rainfall received during 2020 cropping season was 764.4 and 832.8mm at Dera and Melkassa sites respectively. The average monthly maximum and minimum rainfall distribution and relative humidity of the sites were suitable for maize production at both sites [20].

Dera and Melkassa sites had the maximum temperature during the month of May (30.90C) and February (32.20C), respectively. The minimum temperature for Dera (8.80C) and Melkassa (9.40C) sites were registered during November 2020. Dera site had 27.4 and 14.20C average maximum and minimum temperature, respectively, while at Melkassa site had 28.6 and 14.30C average maximum and minimum temperature, respectively [21].

Analysis of variance for yield and yield related traits

The results from analysis of variance (ANOVA) for 13 yield and yield related traits of eight maize hybrids at individual location. Ear length, number of kernel per ear, thousand kernel weight, grain yield, biomass yield and harvest index were significantly influenced by N and genotype at both locations. In addition, these traits except number of kernel per ear and biomass yield were significantly influenced by the interaction of N x genotype at both locations. The application of Nitrogen had significant effect on plant height and leaf area index at both locations while a day to maturity was significantly influenced by N and genotype at Dera and Melkassa, respectively. Neither Nitrogen nor genotype had significant effect on days to emergence, days to 50% tasselling, days to 50% silking and number of ear per plant.at both locations [22].

The results indicated that the eight maize hybrids had significant variations for yield and yield components, and nitrogen fertilizer had significant effect on the performances of hybrids on plant height, leaf area index, yield, and yield components at both locations. Grain yield, ear length, thousand kernel weight and harvest index) were significantly influenced by the interaction of genotype and nitrogen fertilizer rates indicated that the hybrids had differential response to the applied rates of nitrogen fertilizer on the performances of these traits. The effects of nitrogen fertilizer rates on maize hybrids on phenology, growth traits, yield and yield components at different sites and years were reported by many authors, which was in agreement of the current study results [23]. There was a significant difference among five maize genotypes for grain yield, thousand seed weight and harvest index evaluated at Bako Tibe in 2013 and 2014 cropping season (Tolera, et al., 2019). Gizaw (2018) also reported that significant variation between two maize varieties for grain yield, ear length and thousand kernel weights and the effect of genotype x nitrogen fertilizer interaction on these traits [24].

The results of combined analysis of variance over locations. Nitrogen had revealed a significant effect on all traits and genotypes also showed significant differences for all traits except plant height and leaf area index. Location had significant effect on all traits except days to physiological maturity, ear length and biomass yield. The interaction between nitrogen and genotype had a significant effect on all traits except days to physiological maturity and plant height. The interactions between location x nitrogen and location x genotype had significant effect on days to maturity and number of kernel per ear. Besides, thousand kernels weight was significantly influenced by the interaction of location x genotype. The interaction of the three factors (location, nitrogen and genotype) had significant effect on only leaf area index and number of kernel per ear [25].

The result of combined ANOVA suggested that the maize hybrids had significant differences to the utilization (uptake) of nitrogen and produce grain yield in response to the rates of nitrogen fertilizer. The significant effect of nitrogen x genotype interaction on all yield and yield related traits except phenology (days to maturity) and plant height indicated the effort of increasing the maize yield and yield related traits should be towards the identification of the responsive maize hybrids to nitrogen fertilizer and produce high yield [26]. The presence of significant differences for genotypes x nitrogen interaction, and three way interaction (location x genotype x nitrogen) for maize hybrids were reported by many authors. Seyoum et al. (2019) who reported that significant differences among ten maize hybrids for grain yield, thousand kernels weight, leaf area index and harvest index evaluated at four sites (Bako, Hawassa, Melkassa and Adamitulu) in 2013 and 2014 cropping season. The result was in agreement with the finding of (Tadesse and Kim, 2015) who reported that significant variation on maize variety for grain yield, leaf area index, 1000 kernels weight, above ground biomass and harvest index and the interaction of genotype x nitrogen fertilizer effects on these traits evaluated at two sites (Melkassa and Adamitulu) in 2014 main cropping season [27].

Effects of location, nitrogen and genotype on yield and yield related traits

Interaction effect of nitrogen x genotype on ear length

Ear length was significantly influenced by the interaction effect of nitrogen and genotype. The genotype WE8206 with the application of 65 N kg/ha had significantly produced a longer ear length (24.31cm) and, followed by the genotype WE7210 with the application of 32.5 N kg/ha obtained the longer ear length (22.04cm) as compared to other genotypes. The standard check variety, MH138Q was registered a shorter ear length (15.19) at the control plot; however, it had statistically non-significant difference with ear length of other two genotypes obtained from control plots. Ear length of this hybrid (MH138Q) in the control plot had statistically nonsignificant with the application of 32.5 N kg/ha. The results showed that the hybrids had genetic variation on ear length and had differential response to the rates of N for ear length. The result is in line with (Ahmad et al., 2018) reported that ear length was significantly influenced due to varieties [28]. This result is also supported by (Anjorin and Ogunniyan, 2014) who reported that the increase in nitrogen levels positively influence ear length of maize (Table 4).

Interaction effect of location x nitrogen x genotype on number of kernels per ear

Number of kernels per ear was significantly influenced by the three way interactions of location, genotype and nitrogen. The two hybrids (WE8206 and WE7210) recorded significantly highest number of kernels per ear (517.33) and (503.73) at Melkassa site with the application of 65 N kg/ha) respectively. The hybrids at both locations (Dera and Melkassa) due to the application of 65 N kg/ha had statistically nonsignificant number of kernels per ear. The lowest (111.83) number of kernels per ear was recorded for standard check variety of MH138Q at Dera on plots that did not receive fertilizer (control plot). However, the number of kernels per ear of this hybrid had nonsignificant difference with WE5202 and MH140 at Dera site at control plot. The results of the research indicated that as N rates increased the number of kernels per ear of maize hybrids also increased at two locations, but some of the hybrids had higher number of kernels per ear than others in response of the rates of nitrogen at both locations [29].

Maize cultivars having longer ear length (more number of kernels per row) could produce more number of kernels per ear because number of kernels per ear is the result of number of rows per ear x number of kernels per row (Belay and Adare, 2020). The result is in accordance with report of (Hejazi and Soleyman, 2014) who reported that the number of kernels per ear was significantly affected by variety (Table 5) [30].

Interaction effect of genotype x nitrogen and genotype x location thousand kernels weight

Statistical data analysis of variance indicated that two-way interaction of nitrogen and genotype had a significant effect on thousand kernel weight. The highest thousand kernel weight (395.28g) was obtained from WE8206 at plots that were treated with 65 N kg/ha. The lowest (206.67g) thousand kernel weight was measured for WE5202 from the control treatment; however, it had statistically nonsignificant difference with thousand kernel weight of other four hybrids obtained from control plots. Thousand kernel weight of this hybrid (WE5202) increased by 49.76 and 49.72% than control plot due to the application of 32.5 and 65 N kg/ha, respectively, that had statistically nonsignificant difference with thousand kernel weight

Table 4: Interaction effect of Genotype x Nitrogen on ear length of eight maize hybrids at two locations during 2020 cropping season.

	N rate (kg ha^{-1})		
Genotype	0	32.5	65
WE5202	17.56e-h	17.74efg	16.55g-j
WE6205	16.24ijk	16.54g-j	20.97bc
WE7201	15.95jk	18.85de	16.78g-j
WE7210	18.60def	22.04ab	21.74b
WE8203	16.31h-k	16.52g-k	21.15b
WE8206	19.76cd	21.97b	24.31a
MH138Q	15.19k	15.73jk	16.67g-j
MH140	15.20k	17.31f-i	18.32ef
LSD (5%)		2.01	
Earn values with similar letter(s) in columns and rows had nonsignificant difference at P<0.05, and LSD (5%) = least significant difference at 5% probability level			

Table 5: Interaction effect of Location x Genotype x Nitrogen on number of kernels per ear of eight maize hybrids at two locations during 2020 main cropping season.

		N rate (kg N/ha)		
Genotype	Location	0	32.5	65
WE5202	Dera	156.33qrs	321.67m	358j
WE6205		253.50m-p	328.33l	451.07d-h
WE7201		187.17qr	330l	385.13ij
WE7210		226.83q	366jk	462.47c-g
WE8203		236.83p	303.33mn	387.13ij
WE8206		198.50qr	384.67j	408.67hi
MH138Q		111.83t	340k	447.33d-h
MH140		153.50qrs	338.67k	420.73ghl
WE5202	Melkassa	240p	499.4bc	467.07c-f
WE6205		306.33mn	482.87b-e	488.6bcd
WE7201		266.67m-p	451.6d-h	477.4cde
WE7210		256.67m-p	500.13bc	503.33ab
WE8203		295mno	423.93f-i	475.93cde
WE8206		299.67mno	469.53cde	517.73a
MH138Q		265m-p	442.33e-h	463.13c-g
MH140		296.67mno	444.2e-h	447.13d-h
LSD (5%)			**28.93**	
Mean values with similar letter(s) in columns and rows had nonsignificant difference at P<0.05, and LSD (5%) = least significant difference at 5% probability level				

of that had statistically nonsignificant difference with WE6205 and WE8203 (65 N kg/ha), WE7210 (0, 32.5 and 65 N kg/ha) and WE8206 (32.5 N kg/ha). The hybrid, WE7210 had higher thousand kernel weight at three levels of N (0, 32.5 and 65 kg/ha) as compared to other genotypes. The results showed that the hybrids had a genetic variation for thousand kernel weights and had differential response to the rates of N for kernel weight. This result is in line with (Belay, 2020) who reported that the maximum thousand kernel weight was obtained from Bate maize variety where plants were fertilized with 150 kg NPS and 87 kg N/ha at Babile. (Ahmad et al., 2018) also reported that 1000-grain weight was significantly affected by the interaction effect of genotype by nitrogen [31].

Thousand kernel weight was significantly influenced by the interaction effect of location and genotype. The highest thousand kernel weight (371.08g) was obtained from the hybrid WE7210 at Melkassa site. The lowest (177.22g) thousand kernel weight was measured from the standard check variety MH138Q at Dera site; but, it had statistically nonsignificant difference with thousand kernel weight of other two genotypes obtained from control plots. Thousand kernel weight of (WE7210) was highest at both locations as compared to other genotypes, and also at Melkassa site the highest thousand kernel weight was recorded as compared to Dera site; however three genotypes were statistically nonsignificant. The research results showed that the hybrids had genetic variation across locations for thousand kernel weight. This result was in harmony with (Abera and Adinew, 2020) who reported that the maximum thousand kernel weight was obtained from maize hybrids (Table 6).

Table 6: Interaction effect of Genotype x Nitrogen and Genotype x Location on thousand kernels weight of eight maize hybrids at two locations during 2020 cropping season.

Genotype	N rate (kg/ha)		Location	
WE5202		206.67i		193.89h
WE6205		243.92hi		205.56gh
WE7201		239.37hi		194.11h
WE7210	0	319.87bcd	Dera	253.67f
WE8203		261.90fgh		242.22fg
WE8206		250.35ghi		262.11e
MH138Q		240.50hi		177.22h
MH140		263.05fgh		212.78gh
WE5202		309.85b-e		318.74cd
WE6205		303.92c-f		345.82abc
WE7201		290.18d-g		316.70cd
WE7210	32.5	329.75bcd	Melkassa	371.08a
WE8203		268.17e-h		306.50de
WE8206		330.00bcd		354.98ab
MH138Q		276.17e-h		327.52bcd
MH140		297.85c-f		316.29cd
WE5202		309.43b-e	LSD (5%)	31.59
WE6205		339.23bc		
WE7201		296.67c-f		
WE7210	65	347.50b		
WE8203		353.02b		
WE8206		395.28a		
MH138Q		300.45c-f		
MH140		292.70d-g		
LSD (5%)		26.87		

Mean values with similar letter(s) in columns and rows had nonsignificant difference at P<0.05, and LSD (5%) = least significant difference at 5% probability level

Interaction effect of nitrogen x genotype on biomass and grain yield

Aboveground biomass

The results of analysis of variance indicated that the two-way interaction of nitrogen and genotype had a significant effect on biomass yield. The maximum biomass yield (28011kg) was obtained from WE7210 at a plot that received 65 N kg/ha while, the lowest (19003kg) biomass yield was obtained from the variety WE7201 at the control plot. Biomass yield of this hybrid (WE7201) increased by 25.24 and 26.43% than control plot due to the application of 32.5 and 65 N kg/ha, respectively, that had statistically nonsignificant difference with biomass yield of WE5202 (65 kg N/ha) and WE6205 (32.5kg N/ha and at the control plot) and WE8203 (at the control plot). The hybrid, WE7210 had higher biomass at three levels of N (0, 32.5 and 65 kg/ha) as compared to other genotypes. The research result showed that the hybrids had genetic variation and had differential response to the rates of N for biomass yield. This result is in line with (Belay, 2020) who reported that the maximum biomass yield was obtained from Bate maize variety where plants were fertilized with 150 kg NPS and 87 kg N/ha at Babile.

Grain yield

The results of analysis of variance revealed that the interaction of nitrogen and genotype had a significant effect on grain yield. The highest grain yield (8390 kg) was obtained from WE8206 at a plot that was treated with 65 N kg/ha while, the lowest (3489kg) grain yield was obtained from the standard check variety of MH138Q at the control plot. Grain yield of this hybrid (WE8206) increased by 47.31 % and 14.63 % than control plot due to the application of 32.5 and 65 N kg/ha respectively, that had statistically nonsignificant difference with grain yield of the genotypes WE7210, WE7201 and WE8203 (65 N kg/ha). This hybrid, WE8206 also had higher grain yield at three levels of N (0, 32.5 and 65 kg/ha) as compared to other genotypes. The results of research revealed that the hybrids had genetic variation in grain yield and had differential response to the rates of N for grain yield. The result was in harmony with the finding of (Belay and Adare, 2020) who reported that significant differences between maize varieties for grain yield, evaluated at Haramaya in 2018 and 2019 cropping season under rain-fed condition. Belete et al. (2018) also obtained significant difference among three wheat varieties for grain yield, evaluated at Enewari in 2014 and 2015 cropping season [32].

Harvest index

The harvest index of a crop is an interaction of its physiological efficiency and its ability to convert the photosynthetic material into economic yield. Harvest index was significantly influenced by the interaction effect of nitrogen and genotype. The maximum harvest index (39.61%)) was obtained from the variety WE8206 where plots was treated with 65 kg N/ha however, two genotypes (WE7210 and WE 7201) had statistically nonsignificant difference with the application of 65kg N/ha for harvest index. The lowest (25.51%) harvest index was noted from the standard check variety MH138Q at a plot did not receive fertilizer application. The genotype, WE8206 had higher harvest index at the three levels of N (0, 32.5 and 65kg/ha) and its overall mean of harvest index was significantly higher than other hybrids. The research results indicated that the hybrids had genetic variation and differential response to the rates of N for harvest index. Similarly, (Qahar and Ahmad, 2016) who reported that higher harvest index was found from variety R-2210 and from the highest nitrogen fertilizer rate (350 kg N/ha). Belay (2020) also stated that harvest index was significantly affected by the interaction of genotype and N rate (Table 7) [33].

Yield response of maize hybrids to nitrogen fertilizer application

The combined mean values of eight maize hybrids for grain yield obtained from the application of two rates of nitrogen fertilizer (32.5 and 65 kg N/ha) as well as without nitrogen fertilizer application, N nutrient stress (0 kg N/ha) over two locations are presented in (Figure 3).

The mean grain yield of the hybrids (WE8206 and WE7210) was obtained highest grain yield over the standard check variety without N fertilizer application while, the genotypes (WE7210 and WE6205), and WE8206 treated with 32.5 and 65 kg N/ha application had obtained highest grain yield than other hybrids, respectively. The application of 32.5 and 65 kg N/ha had yield advantages of.65.8 and 89.7%, respectively, over yield of maize hybrids obtained without nitrogen fertilizer application. The mean yield of hybrids obtained by application of 65 kg N/ha had yield advantage of 14.4% over the yield of maize hybrids obtained with the application 32.5 kg N/ha. The lowest mean grain yield was observed for the standard check variety (MH138Q) where the plot treated without N application whereas, the two standard check variety (MH 138Q and MH140), and WE5202 had registered the lowest mean grain yield due to the application of 32.5 and 65 kg N/ha, respectively, as compared to other hybrids. This result is in line with (Workneh et al., 2021) who reported that significant variation was obtained for maize variety, evaluated at three sites (Bako, Central rift valley and Jimma) in 2015 and 2016 cropping season [34].

Table 7: Interaction effect of Genotype x Nitrogen on biomass yield, grain yield and harvest index of eight maize hybrids at two locations during 2020 cropping season.

N rate (kg/ha)	Genotype	BY (kg/ha)	GY (kg/ha)	HI (%)
0	WE5202	20167fgh	3831h	28.81g
	WE6205	19667hi	3777h	29.32ef
	WE7201	19003i	3833h	27.21gh
	WE7210	22167efg	4367g	29.59ef
	WE8203	19509ghi	3809h	30.56de
	WE8206	22500def	4421g	31.55cde
	MH138Q	22164efg	3489i	25.51h
	MH140	21161fgh	4001h	29.98ef
32.5	WE5202	25167a-d	6500ef	30.67de
	WE6205	19333ghi	7310bc	31.22cde
	WE7201	25419a-d	6330ef	32.66cde
	WE7210	24667a-e	7333bc	30.74de
	WE8203	26333ab	7159bcd	34.91b
	WE8206	24500a-e	7162bcd	31.28cde
	MH138Q	24333a-e	6166fg	32.01cde
	MH140	22502def	6159fg	30.08de
65	WE5202	19833hi	6033ef	28.03g
	WE6205	24830a-e	7533cde	33.44bc
	WE7201	25833a-d	8103ab	36.01ab
	WE7210	28011a	8159ab	37.84ab
	WE8203	27000abc	8092ab	34.80b
	WE8206	27167abc	8390a	39.61a
	MH138Q	25167a-d	7959bcd	31.11cde
	MH140	24332a-e	7364def	32.35cde
LSD (5%)		79.58	62.11	3.02

Mean values with similar letter(s) in column had nonsignificant difference at P<0.05. BY=Biomass yield (kg ha-1), GY = Grain yield (kg ha-1), HI =Harvest index (%) and LSD (5%) = least significant difference at 5% probability level

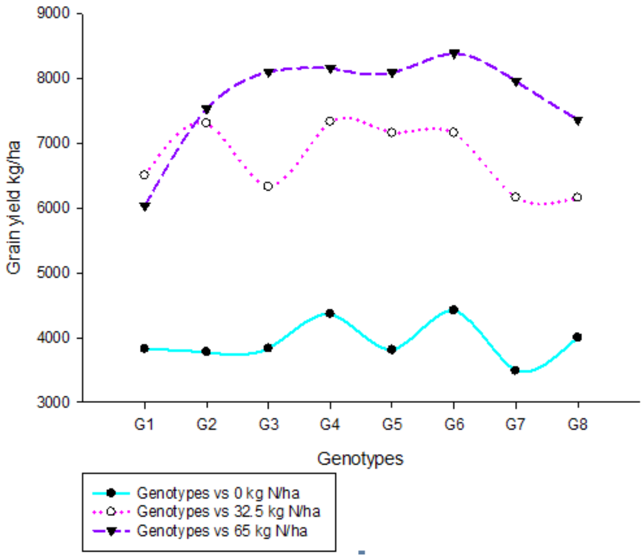

Figure 3: Combiled analysis of grain yield of eight maize hybrids in response to three levels of N evaluated at Dera and Melkassa sites during 2020 main cropping season.

Interaction effect of nitrogen x genotype on crop growth rate

The maximum and significantly highest crop growth rate (23.61g-2 day-1) was observed for hybrid WE8206 where it was treated with 65 kg N/ha. The hybrid, WE 7210 also had higher growth rate of 21.11 g-2 day-1due to the application of 65 kg N/ha though it had nonsignificant difference with other hybrids at different rates of N/ha including at control plot. The two hybrids, namely, WE 5202 and WE 7201 showed higher growth rate at control plot and plots received 32.5 kg N/ha, but had very low growth rate at plots received of 65 kg N/ha. In contrast, all the other hybrids showed higher growth rate at plots received of 65 kg N/ha and lower growth rate at control plot. The mean crop growth rate of hybrids was higher due to the application of 65 kg N/ha and WE 8206, WE 7201 and WE 5202 hybrids had high overall mean crop growth rate of 20.61, 19.53 and 19.47g-2 day-1, respectively, than other hybrids. The result indicated that the maize hybrids had genotypic variation and differential response to the rates of nitrogen application for crop growth rate. This suggested that the importance of identifying maize hybrids efficient in uptake of available nitrogen nutrient to accumulate high dry matter (crop growth rate) in moisture and nitrogen stress areas to obtain higher biomass yield. Similarly, (Tanveer et al., 2013) who reported that crop growth rate was significantly affected by nitrogen x genotype interaction (Table 8).

Interaction effect of location x nitrogen x genotype on agronomic efficiency

The hybrid WE7201 had significantly highest agronomic efficiency of 27.67 kg grain kg-1 nitrogen at plot received 32.5 kg N/ha at Melkassa, while WE 8203 had lowest agronomic efficiency (13.43 kg grain kg-1 nitrogen) at plot that received 65 kg N/ha at Dera. The hybrids except WE 8203 and WE 8203 had higher agronomic efficiency by about 4.74 kg grain kg-1 nitrogen at Melkassa due to the application of 32.5 kg N/ha than the application of 65 kg N/ha. There was variation among hybrids for the reduction of agronomic efficiency at plots that received 65 kg N/ha in which WE7201 hybrid had highest reduction of 13.67 kg grain kg-1 nitrogen followed by WE7210 hybrid

Table 8: Interaction effect of Nitrogen x Genotype on crop growth rate of (g^{-2} day^{-1}) eight maize hybrids at two locations during 2020 cropping season.

	N rate (kg ha^{-1})		
Genotype	0	32.5	65
WE5202	19.89b-f	20.31bcd	18.22efg
WE6205	16.25gh	18.08fg	20.74bc
WE7201	20.10b-e	20.70bc	17.79g
WE7210	16.58g	20.40bcd	21.11b
WE8203	18,20efg	17.76fg	20.37bcd
WE8206	18.57d-g	19.66b-g	23.61a
MH138Q	16.23gh	17.32g	19.94b-e
MH140	16.04h	19.60c-g	19.71b-g
LSD (5%)		3.86	

Mean values with similar letter(s) in column of each trait had nonsignificant difference at P<0.05 and LSD (5%) = least significant difference at 5% probability level

Table 9: Interaction effect of Location x Genotype x Nitrogen on agronomic efficiency (kg grain kg-1 applied nutrients) of N of eight maize hybrids at two locations during 2020 main cropping season.

		Nrate (kgN/ha)	
Genotype	Location	32.5	65
WE5202	Dera	22.22b-g	19.30d-k
WE6205		21.02c-h	17.23i-n
WE7201		20.08c-j	14.41mn
WE7210		23.31b-e	19.08e-l
WE8203		14.67lmn	13.43n
WE8206		20.02c-j	17.69h-n
MH138Q		19.56c-i	16.01j-n
MH140		19.33d-k	16.39j-n
WE5202	Melkassa	24.59b	19.00e-l
WE6205		24bc	17.33i-n
WE7201		27.67a	14mn
WE7210		22.60b-f	15k-n
WE8203		19.04e-l	18.33f-m
WE8206		23.33b-e	18g-n
MH138Q		23.05b-e	17.57h-n
MH140		20.06c-j	16j-n
LSD (5%)		6.42	

Mean values with similar letter(s) in columns and rows had nonsignificant difference at P<0.05, and LSD (5%) = least significant difference at 5% probability level

with the reduction of 7.6 kg grain kg-1 nitrogen than AE at plots that received 32.5 kg N/ha. Whereas hybrids WE8203 and WE8203 showed lower agronomic efficiency reduction of 0.71 and 1.24 kg grain kg-1 nitrogen, respectively, at plots that received 65 kg N/ha than plots received 32.5 kg N/ha. This showed that the agronomic efficiency of hybrids was significantly influenced by location and rates of nitrogen. The results suggested that the higher chance of identifying hybrids with higher agronomic efficiency in response of low rate of nitrogen at both locations and/or specific location than others as stable and/or fit to specific location. Maize crop had a genotypic variation in nitrate absorption and partitioning of N among plant parts (Chevalier and Schrader. 1977). This result is in line with the reports of (Shiferaw, et al., 2018) that significant differences for maize varieties for agronomic efficiency, evaluated at two sites (Addis Alem and Tepi) in 2016 cropping season (Table 9).

Interaction effect of location x nitrogen x genotype on physiological efficiency

The hybrid WE8206 had significantly highest physiological efficiency of 43.52 kg grain kg-1 nitrogen at plot received 32.5 kg N/ha, while the standard check variety MH138Q had lowest physiological efficiency (12.56 kg kg-1kg grain kg-1 nitrogen) at plot that received 65 kg N/ha at Melkassa site. Most of maize genotypes had significantly higher physiological efficiency with the application of 32.5 kg N/ha than the application of 65 kg N/ha at Melkassa site as compared to Dera. There was variation among hybrids for the reduction of physiological efficiency at plots that received 65 kg N/ha in which the standard check variety WE6205 hybrid had highest reduction of 19.21 kg grain kg-1 nitrogen followed by MH138Q hybrid with the reduction of 18.03 kg grain kg-1 nitrogen than PE at plots that received 32.5 kg N/ha. Whereas hybrid WE5202 showed lower physiological efficiency reduction of 3.56 kg grain kg-1 nitrogen, at plots that received 65 kg N/ha than plots received 32.5 kg N/ha. The results of the research showed that the physiological efficiency of hybrids was significantly influenced by location and rates of nitrogen. The results suggested that the higher chance of identifying hybrids with higher physiological efficiency in response of low rates of nitrogen at locations and/or specific location than others as stable and/or fit to specific location. Similarly, (Workneh, et al., 2021) reported that significant differences for maize variety on physiological efficiency, evaluated at three sites (Bako, Central rift valley and Jimma) in 2015 and 2016 cropping season. This result is in agreement with the reports of (Sadegh, 2017) that significant variation among three soybean cultivars for physiological efficiency, evaluated at Babol in 2012 and 2013 cropping season [35].

Conclusions

The central rift valley part of Ethiopia is one of the semi-arid areas in the country where the production of crops is suffering with moisture stress. The climate change and variability pose a serious threat to food production in this area contributed significantly to the water scarcity and with nutrient stress such as nitrogen. Thus the development of varieties to moisture stress areas is one of the strategies to withstand the maize production problems brought by water scarcity and temperature increase.

The results of analysis of variance for individual locations indicated that nitrogen and genotypes had a significant effect on leaf area index, ear length, number of kernel per ear, thousand kernel weight, grain yield, biomass yield and harvest index at both locations. In addition, days to physiological maturity and plant height at Dera site and plant height at Melkassa was significantly influenced by nitrogen levels. Genotype had also significantly influence days to physiological maturity at Melkassa site. Nitrogen and genotypes interacted to influence ear length, thousand kernel weight, grain yield and harvest index at both locations, but leaf area index was significantly influenced by the interaction of nitrogen and genotypes at Melkassa site. The results of combined analysis of variance across locations indicated that the interaction of the interaction of between nitrogen and genotype had significant effect on all traits except days to physiological maturity and plant height. The interactions between location x nitrogen and location x genotype had significant effect on days to maturity and number of kernel per ear. Besides, thousand kernels weight was significantly influenced by the interaction of location x genotype. The interaction of the three factors (location, nitrogen and genotype) had significant effect on only leaf area index and number of kernel per ear.

The genotypes also had significant differences for crop growth rate, agronomic and physiological efficiency. These traits were significantly influenced by one or more than one of the possible two factors interactions (nitrogen x genotype, location x nitrogen, and location x genotype). The interaction of the three factors (location, nitrogen and genotype) had significant effect on leaf area index, number of kernel per ear, agronomic and physiological efficiency. This showed that the importance of identifying genotypes with high yield and nitrogen use efficiency to increase the productivity of the crop in the study areas.

The physiological maturity, most of the plant growth traits, yield components, agronomic and physiological efficiency were the function of genotype and nitrogen and/or the interaction of the two factors. Thus, the effort of enhancing nitrogen use efficiency of the maize genotypes in the study areas needs to be towards the identification of maize hybrids efficient to the utilization of available nitrogen nutrient at different locations. Hence, WE8206 and WE7210 could be recommended for production in the study areas. However, further studies will be needed, because the two locations have received sufficient rainfall during the experimental year, and the response of the hybrids at both locations with low soil fertility conditions may not be sufficient to represent the semi-arid areas of Ethiopia.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publishing of this work.

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